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The Effect of Cutting Parameters on Tool Wear in Drilling Aluminium 7075

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Abstract:

Drilling is an important process for assembly operation by mechanical fasteners in automotive industry. The drilled holes must achieve a good machined surface quality requirement for part assembly. However, dry drilling of aluminium alloy 7075 is challenging due to the issues of high cutting temperature. Consequently, this can result in shorter tool life. Thus, industry overcome these issues by using coolants in the form of fluid but over the time, the fluids would be contaminated with bacteria which is harmful to the operator and could also lead to environmental issues. As to achieve a hygienic and clean process, this paper proposes to study the optimal cutting parameters in reducing tool wear when drilling aluminium 7075 in dry condition. Drilling experiments were performed using tungsten carbide drill bits at cutting speeds of 4000 to 8000 rpm and feed rates of 0.01 to 0.10 mm/rev. The tool wear was analyzed by measuring the flank of drill bits after drilling every 10 holes. The cutting speed of 4000 rpm and feed rate of 0.01 mm/rev was found to be optimal for drilling aluminium 7075 as it resulted in the least tool wear of 0.024 mm after drilling 70 holes compared to other cutting parameters. Thus, this study indicates that combination of a lower cutting speed with a lower feed rate during drilling of aluminium 7075 is beneficial to improve the life of carbide cutting tool. ***Keywords:*** *Aluminium Alloy, Drilling, Cutting Parameter, Tool Wear.*

I. INTRODUCTION

Aluminium 7075 (Al 7075) had been widely used for various manufacturing industries such as automotive, aerospace and food processing equipment [5]. This is because of the outstanding mechanical properties of Al 7075 such as high specific strength, good corrosion resistance, and good economical values [1]. Al 7075 is highly desirable in the automobile manufacturing industry because of the light weight-to-strength ratio properties when comparing to stainless steel. This can be seen by the density of aluminium, 2700 kg/m^3 that is two to three times lower than stainless steel, 7700 kg/m^3. Though the density values are different, yet the properties in aspects of strength and toughness are almost the same after aluminium being alloyed into Al 7075.

In automobile manufacturing industry, drilling operations are often performed for mechanical assembly of automobile parts. For every automobile manufactured, hundreds of holes need to be drilled including internal parts such as engine blocks, and transmission shafts for assembly purposes. The drilling operation efficiency, which includes the tool frequency changing due to tool wear and failure will affect the production time and cost. Cutting tools made of tungsten carbide tools are typically used in achieving higher drilling performance of Al 7075 because of the low chemical affinity properties that reduces the adhesion wear on the cutting edges [3-6]. Drilling operation is often performed in dry condition since the usage of cutting fluid would affect the cost, health and environment [7]. However, dry drilling could lead to rapid tool failure due to substantial heat generation between cutting tool and workpiece. In addition, drilling Al 7075 can be challenging due to its soft and ductile characteristics which causes Al 7075 to adhere easily at the cutting edges as the cutting temperature increases. This will result in the formation of build-up edge (BUE), that led to higher tool wear, hence, shorter tool life.

Typical types of tool wear that happen when drilling Al 7075 are abrasive, adhesive, and diffusive wear [8]. Temperature of cutting between the tool

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and workpiece could increase after drilling a significant number of holes. This would cause a transition of abrasive to adhesive wear, and over time it will change to diffusive wear. Abrasive wear is influenced by the hardness of workpiece material, and formation of BUE at the cutting edges. When there is contact of the cutting tool flank face with the rigid workpiece, sliding and seizure could occur. The region of tool wear by abrasion is typically shown by scratches parallel to the cutting direction [9]. Abrasive wear can be counteracted by using harder tool material. It was reported that cobalt (HSCo) drill bits performed better by 16% than high speed-steel (HSS) drill bits in tool wear aspects during dry drilling of Al 2024 at 0.04 mm/rev feed rate and 94 m/min cutting speed [10]. This is because HSCo drill bits contain 5-8% of cobalt blended into the base material and it makes its hardness properties higher than HSS drill bits. Therefore, in this study, tungsten carbide had been chosen as the cutting tools for drilling Al 7075 since the hardness and toughness properties is better than HSS based cutting tool.

Nouari *et al.* [11] claimed that tool wear had been controlled by cutting temperature that was generated by friction and plastic deformation in the secondary shear zone. The cutting speed is an important factor in controlling cutting temperature since the heat was generated from the energy dissipated during rotation of the drill bits. In the research, Nouari *et al*. [11] also proved that tungsten carbide tool has 20% longer tool life in which favorable in achieving good quality holes than HSS tool in dry drilling of Al 2024. This is because HSS tool did not hold the good properties in aspect of hardness and toughness as compared to tungsten carbide that led to higher tool wear, hence, shorter tool life [11].

Adhesive wear is governed by high cutting temperature and high pressure due to surface irregularities [12]. The flow-zone where the chip is removed to the tool rake face is the most dominant heat resources that responsible for increment of the tool temperature. So, as the number of holes produced increases, the amount of chip generated also increases. Thus, the cutting temperature of tool interface and workpiece is significantly increasing. As the cutting temperature increases, the workpiece material will adhere at the cutting edge in significant amount consequently resulting in BUE formation. Thus, in order to reduce adhesive wear, lower cutting speed machining is recommended due to low cutting temperature which could lead to a longer tool life. As reported by Arsecularatne *et al.* [13], adhesion usually happened at high cutting temperature with moderate cutting speed of 76 to 198 m/min and it is dominant in dry drilling. Khatri *et al.* [14] investigated the mechanism of tool wear during dry machining of titanium alloy at cutting parameters of 50 m/min of constant cutting speed and various feed rates. It was found that 0.05 mm/rev feed rate produced the lowest adhesive wear and chipping. Adhesion mechanism and higher cutting forces acting on the tool in dry machining cause the edge chipping. Chipping could occur at the tool nose of a drill which causes a change in the cutting tool geometry as the rake angle may become negative. Chipping usually occurred at the flank face and it is often happened in dry condition since there is no medium to cool the heat generated. Besides, adhesion wear was found significantly at the higher feed rate where there was accumulation of workpiece attached to the tool cutting edge. This is also happened due to the high temperature of cutting in dry machining. Thus, in order to avoid this higher tool wear, higher feed rate is typically not recommendable in dry machining [14].

Cutting parameters in drilling have been proposed to have a significant influence in determining the tool wear mechanisms, rates, and tool life. There is a global demand in achieving higher rate of material removal and longer cutting tool life to improve production rate in machining industry [15]. Therefore, the purpose of this paper is to investigate the effect of cutting parameters on tool wear in order to investigate the optimal parameters which could prolong tool life when drilling Al 7075.

II. EXPERIMENTAL SETUP AND PROCEDURE

In this study, aluminium 7075 (Al 7075) was employed throughout all drilling trials. The Al 7075 composition and properties are shown in Tables 1 and 2. The cutting tools used were uncoated tungsten carbide twist drills with 6.5 mm diameter, 2 number of flutes, 30° helix angle, and 118° point angle, as recommended by the manufacturer for drilling aluminium alloy. Tungsten carbide tools is proven in having better wear resistance than HSS tools in drilling aluminium alloy [3-6]. The drilling

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experiment was conducted by using 11.2 kW MAZAK vertical centre nexus 410A-II with maximum spindle speed of 12000 rpm.

The cutting parameters as shown in Table 3 had been chosen based on the machine tool specifications, cutting tool material, and the previous related research. In this study, tool wear was measured by calculating the cutting edges change after drilling every 10^{th} holes in comparison to a fresh cutting edge. The flank wear had been measured by using a USB digital microscope and the initial condition of the drill bit flank face is shown in Figure 2.

Table 1: Properties of Al7075 – T651

Density	2803 kg/m^3	
Mechanical Properties	Tensile strength	85.4 ksi
	Yield strength	78.2 ksi
	Elongation	18.4%

Table 2: Chemical composition of Al7075 – T651 (wt%)

Zn	Mg	Cu	Fe	Si	Mn	Ti	Cr	Al
5.1	2.1	1.2	0.5	0.4	0.3	0.2	0.18	remainder

Table 3: Cutting parameters

Cutting speed (rpm)	4000	6000	8000
Feed rate (mm/rev)	0.01	0.05	0.10

Figure 1: Vertical drilling machine setup

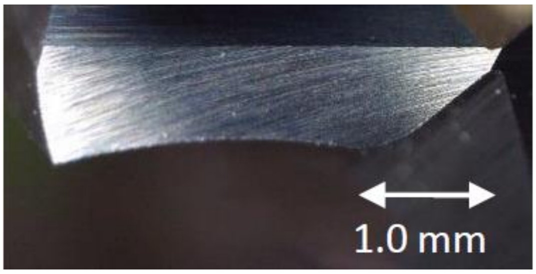
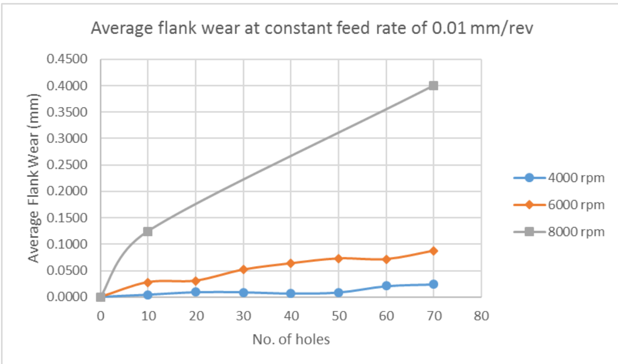


Figure 2: Flank face initial condition

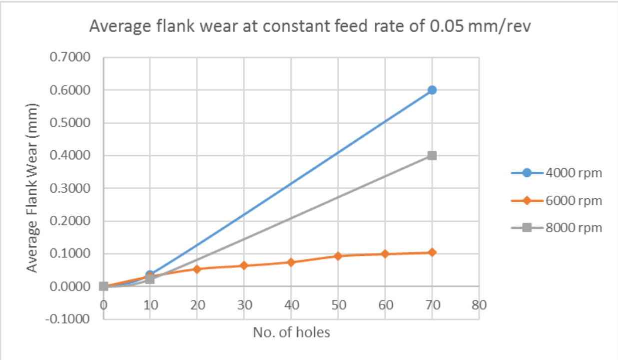
III. ANALYSIS OF TOOL WEAR AND CUTTING PARAMETERS

Drilling Al 7075 resulted in abrasive and adhesive types of wear. Both types of wear usually happened due to the workpiece hardness and high cutting temperature as number of holes being drilled increases. This research aims to investigate the cutting parameters effect in term of mechanisms of tool wear and tool wear rate.

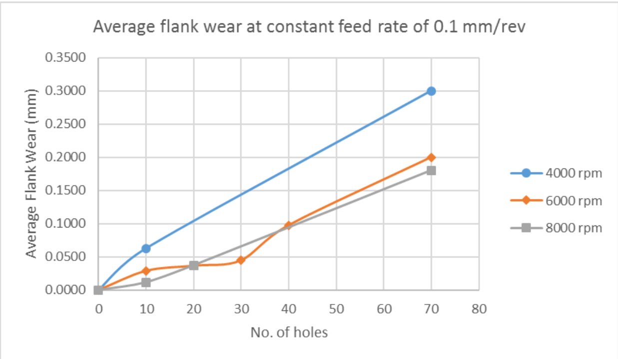
Figures 3 and 4 show a comparison of average flank wear when drilling Al 7075 at constant feed rates and cutting speeds, respectively. As seen in Figures 3(a) and Figure 4 (c), the highest average flank wear occurred when drilling at 8000 rpm cutting speed and 0.01 mm/rev feed rate. This indicates that combination of higher cutting speed and lower feed rate resulted in higher tool wear. The cutting temperature between tool and workpiece increases due to the higher cutting speed. The cutting temperature increment is due to the heat formation when built-up edge occurred during removal of chip at the cutting tool rake face [11,13]. It was reported that, higher tool wear resulted from a higher cutting speed due to rise of the cutting temperature [15]. The particles from tool was dispersed to the chip through the workpiece flow along the contact surface. This resulted in adhesion layer formation and build-up edge at the cutting tool, faster tool wear and consequently, led to the cutting tool breakage. The image of flank face at cutting parameters of 8000 rpm and 0.01 mm/rev is shown in Figure 5. It shows that at the cutting edge, a huge part of flank wear is evident.



(a)



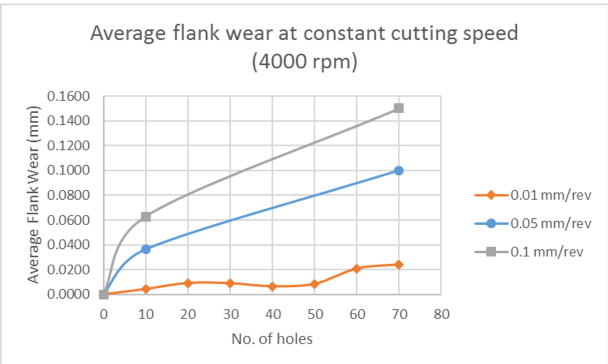
(b)



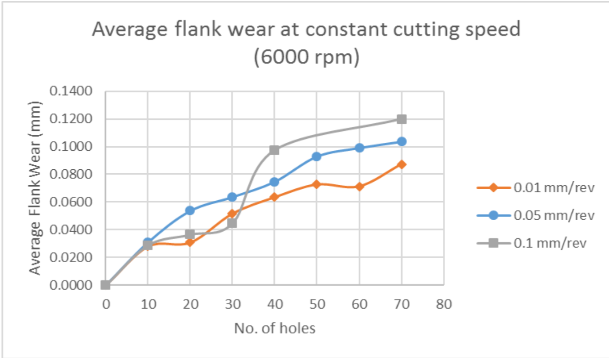
(c)

Figure 3: Average flank wear of carbide drill bits based on number of holes at constant feed rates of (a) 0.01 (b) 0.05 and (c) 0.10 mm/rev.

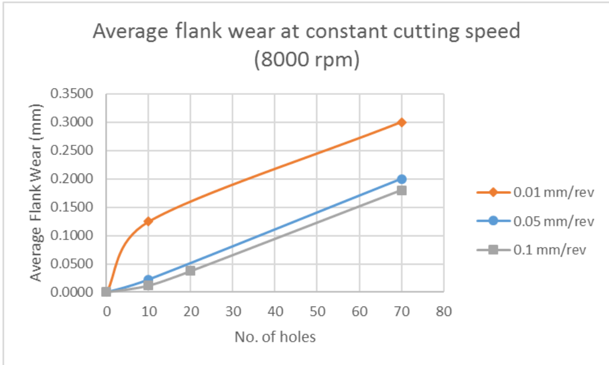
Meanwhile, Figure 3 and 4 (a) share the same result for lowest tool wear at 4000 rpm cutting speed and 0.01 mm/rev. At lower cutting speed, the main mechanism of tool wear is abrasion as indicated in the Figure 5. image of Run 1 (4000 rpm, 0.01 mm/rev). The result from this study is supported by Ashrafi *et al.* [10] findings, which also discovered that at lower cutting speed, the most dominant mechanism of wear is abrasive wear that occurred on the flank face.



(a)



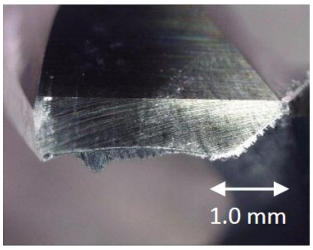
(b)



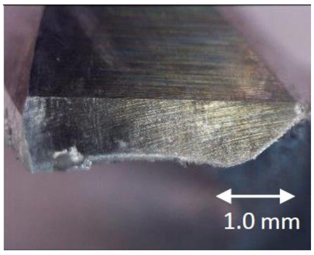
(c)

Figure 4: Average flank wear of carbide drill bits based on number of holes at constant cutting speeds of (a) 4000 (b) 6000 (c) 8000 rpm.

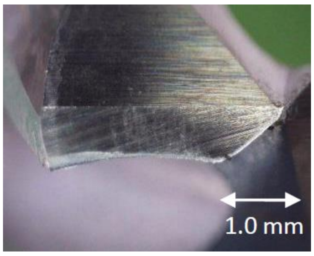
Run 1
4000 rpm
0.01 mm/rev



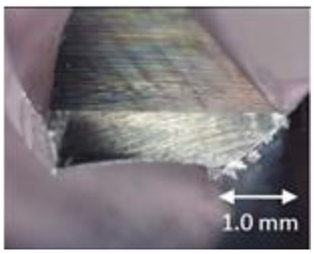
Run 2
6000 rpm
0.01 mm/rev



Run 3
8000 rpm
0.10 mm/rev



Run 4
4000 rpm
0.05 mm/rev



Run 5
6000 rpm
0.05 mm/rev

Run 6
8000 rpm
0.05 mm/rev

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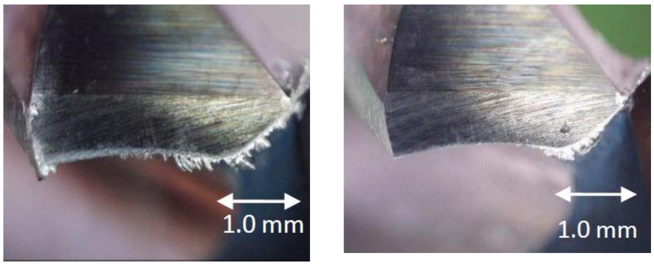
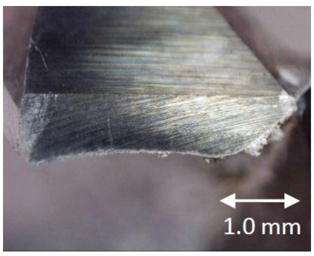


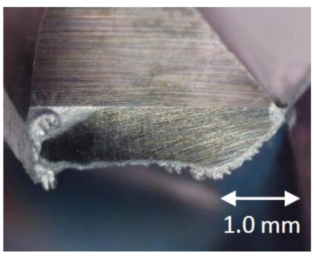
Figure 5: Image as indication of built-up edge and flank wear at the cutting tool.

Figure 3 (b) shows the result of average flank wear that occurred when using a feed rate of 0.05 mm/rev. Based on the trendline, the highest average flank wear is shown at the 4000 rpm cutting speed while the lowest is at 6000 rpm cutting speed. This shows that moderate feed rate and lowest cutting speed combination resulted in higher tool wear as compared to higher cutting speed. Arsecularatne *et al.* [13] reported that at lower cutting speed, carbide tool dominant wear mechanism is abrasion that happened due to the BUE formation since the chip removal rate is slower as compare to drilling at higher cutting speed [18]. Since the feed rate is moderate, the contact time in between the workpiece and cutting tool is longer which mean larger contact area, thus, this combination led to higher tool wear. This tool wear is shown in Figure 5 at Run 4 (4000 rpm, 0.05 mm/rev), where there is BUE formation and chipping that occurs due to adhesion at high cutting temperature. Previous study by Zitoune *et al.* [16] shows that when drilling at 0.05 mm/rev feed rate and lower cutting speed of 1050 rpm, chipping had occurred due to the mechanical adhesion that happened when there is contact between aluminium and cutting tool. Figure 3 (b) shows that after drilling 70 holes at a constant feed rate of 0.05 mm/rev, using a moderate cutting speed of 6000 rpm resulted in the lowest tool wear. This is because as the cutting speed increases, the amount of workpiece bonding on cutting

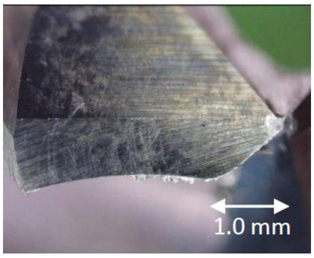
Run 7
4000 rpm
0.1 mm/rev



Run 8
6000 rpm
0.1 mm/rev



Run 9
8000 rpm
0.10 mm/rev



Chipping/Pull out

Figure 6: Image as indication of built-up edge, flank wear, and chipping at the cutting tool.

tool is reducing. The image of the flank wear is shown in Figure 5 at Run 5 (6000 rpm, 0.05 mm/rev).

Figure 3 (c) and Figure 4 (a) show that the highest flank wear occurs at 4000 rpm cutting speed and 0.1 mm/rev feed rate. The flank face of the drill that was used during Run 7 (4000 rpm, 0.10 mm/rev) is shown in Figure 6. There is a formation of BUE due to the adhesion of Al 7075 that occurs due to high cutting temperature. Abrasive wear was observed since there is scratches on the flank face. Even though the flank wear is high (0.063 mm), the drill bit can still be used for further drilling since the wear has not reached the maximum limit of 0.3 mm. Figure 3 and 4 (c) shows a combination higher cutting speed and higher feed rate where the contact time between tool and workpiece was shorter. So, the heat transfer in between tool and workpiece is lesser, hence, slowing the process of abrasion to adhesion wear and decelerating tool wear [8]. This can also be seen at the image of flank wear at Run 9 (8000 rpm, 0.10 mm/rev) in Figure 6, where there is only scratches and minor wear on the cutting edge which is an evident of abrasion mechanism.

When drilling with a constant cutting speed of 6000 rpm, it was found that the highest average flank wear occurs at 0.1 mm/rev feed rate, while the lowest flank wear is at 0.01 mm/rev feed rate, as shown in Figure 4 (b). This indicates that at a constant cutting speed, when the feed rate increases, the average flank wear also increases. This is because of the increasing thrust forces during drilling due to the feed rate increment [17]. The image of lower tool wear for cutting parameters of 6000 rpm and 0.01 mm/rev is shown in Figure 5 at Run 2. As for the higher tool wear, the image of flank is shown in Figure 6 at Run 8 (6000 rpm, 0.10 mm/rev). There is chipping occurrence due to cutting temperature increases as number of holes being drilled increases. The adhesive wear keeps increasing significantly, hence, result in higher tool wear with chipping.

IV. CONCLUSIONS

This study investigates the effect of cutting speeds (range of 4000 to 8000 rpm) and feed rates (0.01 to 0.10 mm/rev) on tool wear in drilling aluminium 7075. In conclusion, findings from this study are outlined as follows:

1. In comparison to feed rate, cutting speed is the governing cutting parameter in controlling tool wear. This can be seen from the significant change of tool wear as cutting speeds change from 4000 to 8000 rpm. Based on previous study, this occurred due to the tool wear rate that is significantly influenced by the cutting temperature in between tool and workpiece.
2. There are two types of wear that had been observed which are abrasive wear at lower cutting speed (4000 rpm) and adhesive wear at higher cutting speed (6000 to 8000 rpm). Previous study found that, at lower cutting speed, abrasive wear happened due to the formation of BUE that occurs because of the slower chip removal rate. Meanwhile, at higher cutting speed, adhesive wear occur due to the higher heat generation that result in higher cutting temperature.
3. It was found that lower cutting speeds within the range of 4000 rpm resulted in minimum tool wear of 0.024 mm. Whereas the use of higher cutting speeds within the range of 8000 rpm resulted in maximum tool wear of 0.12 mm after drilling 10 holes. Therefore, it is recommended to use lower cutting speed in drilling aluminium 7075 as the heat generation is lower than other cutting speeds.

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